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Analytical and sensitivity approaches for the sizing and placement of single DG in radial system

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Abstract. Rapid depletion of fossil based oil, coal and gas reserves and its greater demand day by day necessitates the search for other alternatives. Severe environmental impacts caused by the fossil fire based power plants and the escalating fuel costs are the major challenges faced by the electricity supply industry. Integration of Distributed Generators (DG) especially, wind and solar systems to the grid has been steadily increasing due to the concern of clean environment. This paper focuses on a new simple and fast load flow algorithm named Backward Forward Sweep Algorithm (BFSA) for finding the voltage profile and power losses with the integration of various sizes of DG at different locations. Genetic Algorithm (GA) based BFSA is adopted in finding the optimal location and sizing of DG to attain an improved voltage profile and considerable reduced power loss. Simulation results show that the proposed algorithm is more efficient in finding the optimal location and sizing of DG in 15-bus radial distribution system (RDS).The authenticity of the placement of optimized DG is assured with other DG placement techniques.

Keywords: distributed generator; BFSA; GA; optimal location; voltage profile; RDS

1. Introduction

Electricity supply industry finds it difficult to grow in tune with the increasing demand due to the concern of the depleting of fossil fuel and environmental issues. In many cases, geographic extension of the existing distribution network may not be possible due to environmental and political constraints. The existing systems are driven closer to their limit, resulting in congestions and critical situations of endangering the system security. The restructuring of present infrastructure of the centralized electrical power system with the integration of renewable sources help to manage the ever growing power demand (Babu and Ashok 2009, Gozel and Hocaoglu 2009).

Now-a-days, DG can offer a considerable percentage of reliable power with reasonable power quality standard. High rate of penetration of DG mainly focuses on the global concerns of reducing greenhouse gas emissions and deregulation of the electric energy market. Due to the incremental demands for electrical energy, DG's are becoming more prominent to be used as a supplement to conventional energy sources in future (Jain *et al.* 2014).

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The reliability and operation of power system networks closely depend on the proper integration of DG. Furthermore, improper placement of DG in radial distribution system adversely affects the system losses and thereby the voltage profile (Kirmani *et al.* 2011, Kanth *et al.* 2013). In such situations, the integration of DG gives more privilege to the voltage stability. The benefits of DG are attained by minimizing losses, which improves the performance, reliability and efficiency of the system.

In recent years, the major attracted and concerned issue is the allocation of proper size of DG at an optimal access point in radial distribution systems. Most of the researchers are focused on developing new methodologies to find the optimal position at which a suitable size of DG is to be placed, for improving the voltage profile by reducing the power losses (Dasan and Ramalakshmi 2009). In order to meet the benefits of DG, the size of DG has to be minimized. Several algorithms are proposed by researchers to solve the problem of obtaining the optimized size and location of DG (Ishwarya and Surya 2014). The optimal allocation of DG is formulated as objective function in terms of minimum of active power loss subject to the constraints in terms of the rating of DG and voltages (Mohapatra *et al.* 2012, Shukla *et al.* 2010). Owing to the peculiarities of distribution lines, traditional methods of solving the above said optimization problems like Newton-Raphson method, Fast Decoupled Load Flow method etc. fail to give guaranteed convergence in radial distribution system.

Almost 90% of distribution lines are too long and radial in nature with a specialty of high *R/X* ratio and unbalance in loads (Hung and Mithulananthan 2014). The distribution lines with above features result in a large voltage drop, low voltage stability and large power losses. Backward Forward Sweep Algorithm (BFSA) is a suitable algorithm which gives fast convergence in radial distribution system (Moradi and Abedini 2012). This algorithm involves only simple algebraic expressions of voltage magnitudes. The computer memory required for this algorithm is very less. Guaranteed convergence is another merit of this algorithm (Injeti and Kumar 2013). The distribution feeders are too long and hence the voltages at the far end of the feeders are much affected with poor voltage regulation (Das *et al.* 1995). The integration of proper sized DG at optimal location results in better voltage regulation.

Several optimization techniques such as Particle Swarm Optimization (PSO), Genetic Algorithm (GA) (Hung and Mithulananthan 2014), Ant Colony Algorithm, etc. are used to solve the multi-objective problems like the position and size of multi DG in the radial system (Kayal and Chanda 2013, Mistry and Roy 2012, Mistry and Roy 2012). Most of the researchers found the location and size of DG with the help of tools so that only one possible size and location is found out. The determination of the possible locations and sizing of DG, to compute the power losses and voltage profile at all the nodes using BFSA, has not been found attempted in the literature. In this background, a Genetic Algorithm based BFSA is proposed in this paper, to find the optimal size of single DG with proper placement in a radial distribution system which alleviates the adverse effect such as deployment of losses and degradation of voltage profile. Case study has been conducted to reaffirm the size and position of DG in RDS.

2. Formulation of voltage and power losses

The power loss in a radial distribution system can be effectively reduced with the help of proper placement and sizing of DG. Voltage stability is the major concern of radial distribution system. One of the major constraints in the power system is to maintain the magnitude of bus

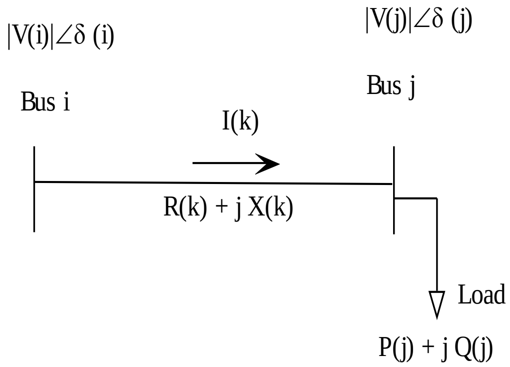


Fig. 1 Radial distribution system with two buses

voltage at an acceptable range. This can be attained with the use of optimized DG which improves the voltage stability.

2.1 Backward Forward Sweep Algorithm (BFSA)

Backward and Forward Sweep Algorithm (BFSA) is the simple, efficient and accurate algorithm that can be implemented to find the voltage profile and hence total real and reactive power losses of a radial distribution system. This method converges very fast since node voltages are evaluated directly from the Kirchhoff's Voltage Law. Since the radial system consists of main feeders as well as lateral feeders, it is necessary to identify the nodes and branches beyond a particular node. BFS algorithm helps in finding the net load feed through each node (Injeti and Kumar 2013).

Consider a two bus network having sending end voltage $V(i)\angle\delta(i)$ and receiving end voltage $V(j)\angle\delta(j)$. The load at bus *j* is *P*(*j*)+*Q*(*j*). Line shunt capacitance is negligible at distribution voltage level. *I*(*k*) is the current flowing from bus *i* to bus *j* (Das *et al.* 1995).

$$I(k) = \frac{|V(i)|\angle\delta(i) - |V(j)|\angle\delta(j)}{R(k) + jX(k)} \tag{1}$$

Also

$$I(k) = \frac{P(j) - jQ(j)}{V^*(j)} \tag{2}$$

From the above Eqs. (1) and (2)

$$\frac{|V(i)|\angle\delta(i) - |V(j)|\angle\delta(j)}{R(k) + jX(k)} = \frac{P(j) - jQ(j)}{V^*(j)} \tag{3}$$

therefore

$$|V(i)||V(j)|\angle\delta(i) - \angle\delta(j) - |V(j)|^2 = [P(j) - jQ(j)][R(k) + jX(k)] \tag{4}$$

$$\begin{aligned}&|V(i)||V(j)|\cos[\delta(i) - \delta(j)] - |V(j)|^2 + j|V(i)||V(j)|\sin[\delta(1) - \delta(2)] = \\ &[P(j)R(k) + Q(j)X(k)] + j[P(j)X(k) - Q(j)R(k)]\end{aligned} \tag{5}$$

Separating real and imaginary parts of the Eq. (5)

$$|V(i)||V(j)|\cos[\delta(i) - \delta(j)] - |V(j)|^2 = [P(j)R(k) + Q(j)X(k)] \tag{6}$$

$$|V(i)||V(j)|\sin[\delta(i) - \delta(j)] = [P(j)X(k) - Q(j)R(k)] \tag{7}$$

Squaring and adding the Eqs. (6)-(7)

$$|V(i)|^2|V(j)|^2 = \left[|V(j)|^2 + P(j)R(k) + Q(j)X(k)\right]^2 + [P(j)X(k) - Q(j)R(k)]^2 \tag{8}$$

or

$$|V(j)|^4 + 2\left[P(j)R(k) + Q(j)X(k) - 0.5|V(i)|^2\right]|V(j)|^2 + (R^2(k) + X^2(k))(P^2(j) + Q^2(j)) = 0 \tag{9}$$

The solution of Eq. (9),

Voltage at j^{th} bus is

$$|V(j)| = \left\{\left[\begin{array}{l}\left(P(j)R(k) + Q(j)X(k) - 0.5|V(i)|^2\right)^2 \\ -\left(R^2(k) + X^2(k)\right)\left(P^2(j) + Q^2(j)\right)\end{array}\right]^{1/2} - \left(P(j)R(k) + Q(j)X(k) - 0.5|V(i)|^2\right)\right\}^{1/2} \tag{10}$$

Real and reactive power losses are

$$P_{loss} = R(k) * [P^2(j) + Q^2(j)] / |V(j)|^2 \tag{11}$$

$$Q_{loss} = X(k) * [P^2(j) + Q^2(j)] / |V(j)|^2 \tag{12}$$

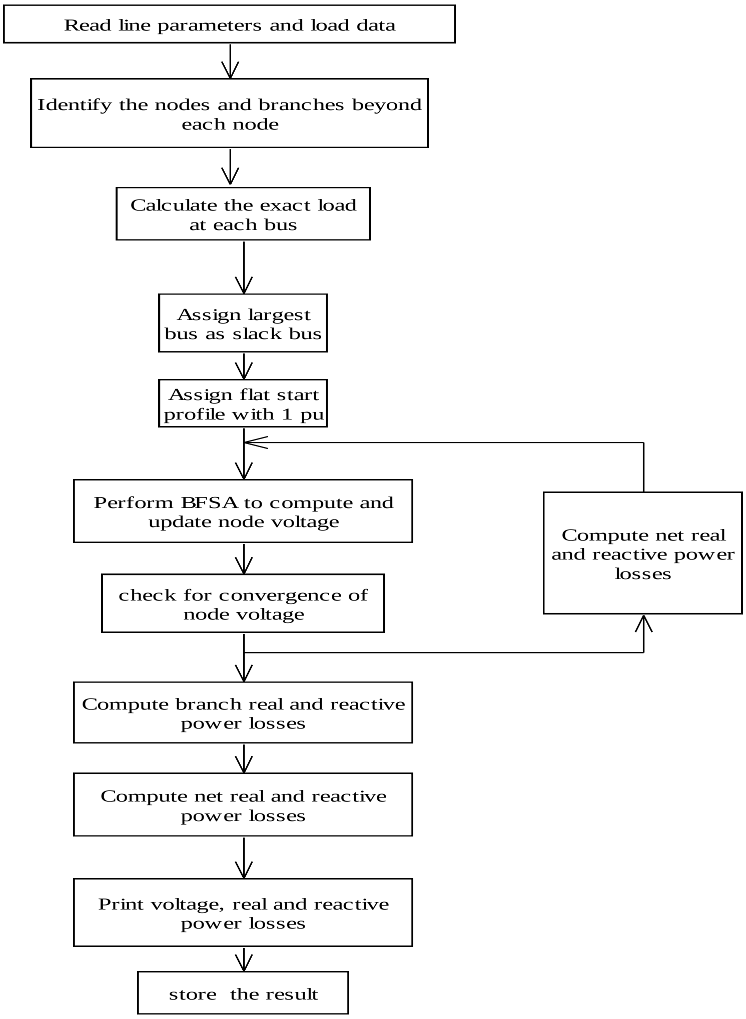
where *P*(*j*) and *Q*(*j*) are total real and reactive power loads through node *j*.

P(*j*)=sum of real power loads of all the nodes beyond node *j* plus real power load of node *j* itself plus sum of real power losses (P_{loss})of all the branches beyond node *j*.

Q(*j*)=sum of reactive power loads of all the nodes beyond node *j* plus reactive power load of node *j* itself plus sum of reactive power losses (Q_{loss}) of all the branches beyond node *j*.

For load flow analysis using MATLAB, the nodes and branches beyond a particular node has to be identified which help in finding the exact load feeding through that particular node. If all the nodes and branches are identified, it is very easy to calculate voltage magnitudes at nodes with the help of the above equations. In successive iterations, if difference between real and reactive power delivered from the substation is less than 0.1 kW and 0.1 kVAr, the solution is converged. The above algorithm is used to find the voltage at different nodes and active and reactive power losses at the different branches. Active and reactive supports are given to the branch having high active and reactive power loss by means of DG and FACTs devices so as to maintain the voltage stability.

2.2 Algorithm for BFSA



3. Problem formulation

With the introduction of Distributed Generation in a radial distribution system, the improvement of voltage profile can be accomplished only with the finding of proper placement and sizing of DG. The prime objective of such a system is to improve the voltage profile by minimizing the network power losses. Out of the best optimization techniques such as Genetic Algorithm (GA), Particle Swarm Optimization (PSO) etc., GA is preferred to find the optimal access point and capacity of DG in the radial system. Certain assumptions are considered for the placement of DG. The DG is considered as negative load which injects only active power. The total load demanded plus total loss of the system is considered to be equal to the maximum size of DG (Shrivastava *et.al* 2012). The bus, at which the load is connected, is the possible location of DG. Source node or substation cannot be considered as the location for a DG.

3.1 Objective function

The total active power loss in a radial distribution system with N-1 branches is given by

$$P_{loss} = \sum_{k=1}^{N-1} R(k) * |P^2(j) + Q^2(j)| / |V(j)| \tag{13}$$

N-Number of buses, 'i' is the sending end node, 'j' is the receiving end node and k is the branch between i^{th} and j^{th} node. The objective function is to minimize the active power loss subject to the constraints (Dasan and Ramalakshmi 2009).

$$|V_i| \leq 1 \pm 0.05\text{pu}, i = 1,2,3,\ldots\ldots\ldots\ldots N$$

$$0 \leq P_{DG} \leq P_{Load} \quad P_{Load} - \text{total connected load in the system}$$

3.2 Algorithm for single DG placement

The DG is modeled as negative load and injects real power only. Modeling DG units as negative loads can have a positive impact on the reliability of the network. Wind model is taken as DG and it is connected in parallel to the load point of the distribution network.

Real power at node j, $P_j = P_L - P_{DG}$

Reactive power at node j, $Q_j = Q_L - Q_{DG}$ where P_L and Q_L are the real and reactive power of the load connected to j^{th}node and P_{DG} and Q_{DG} are the real and reactive power of the DG connected to j^{th} node. Q_{DG} is taken as 0 KVAr. GA is used to optimize the size of DG so that real power loss of the network can be minimized. The size of DG in KW is taken as the chromosomes represented by x, so that the objective function is written as

$$g_{(x)} = \text{Ploss}_{(x)\text{with DG}} / \text{Ploss}_{(\text{without DG})}$$

Where $Ploss_{(x)with\,DG}$ is the total network real power line loss with DG of 'x' KW rating. The active power generated by each DG (P_{DG}) is restricted within the range of P_{DG} min and P_{DG} max.

Here P_{DG} min is 0 KW and P_{DG} max is 1.5 MW. The system losses and bus voltages are computed with the help of BFS algorithm by placing DG of size varying from 0 to 1.5 MW with a step size of 0.1 MW at all buses. Since the objective function is to minimize the system losses, the fitness function is taken as

$$f(x) = \frac{1}{1 + g(x)}$$

GA helps in finding the suitable size of DG and location having minimum system loss and improvement in voltage profile. The coding used to represent the DG capacity is binary type coding in which 0000 means NO DG unit or 0KW and 1111 means 15 DG units of 0.1 MW, i.e., 1.5 MW. Decoding of the GA solution is based on the same idea by translating a number in the chromosome into the respective DG unit. The algorithm for finding the size and position of DG is explained as below.

Algorithm:

Step 1: Conduct load flow analysis for the original system without DG and find node voltages,

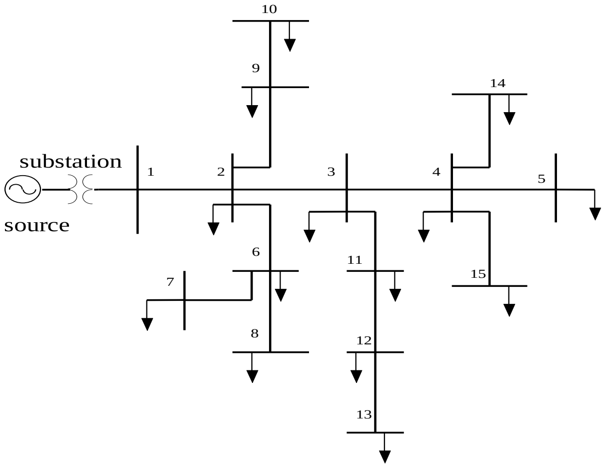


Fig. 2 Single line diagram 0f 15 bus, 11 KV radial distribution system

net real and reactive power losses.

Step 2: Set the bus number (*i*) of DG as one.

Step 3: If bus number is greater than total no. of bus (*N*), then find the minimum active power loss otherwise, set size of DG (P_{DG})as zero.

Step 4: If P_{DG} is greater than net active load, bus number is incremented by one. Otherwise, run power flow and calculate active power loss.

Step 5: Then DG size is incremented with a step size of 1 kW.

Step 6: Check the node voltage less than 1±0.05 pu. Otherwise reject unsuitable values and go to step 3.

Step 7: For minimum active power loss, find the optimum location (*i*) and size (P_{DG}) of DG.

Step 8: Conduct load flow by placing P_{DG} at the optimal location.

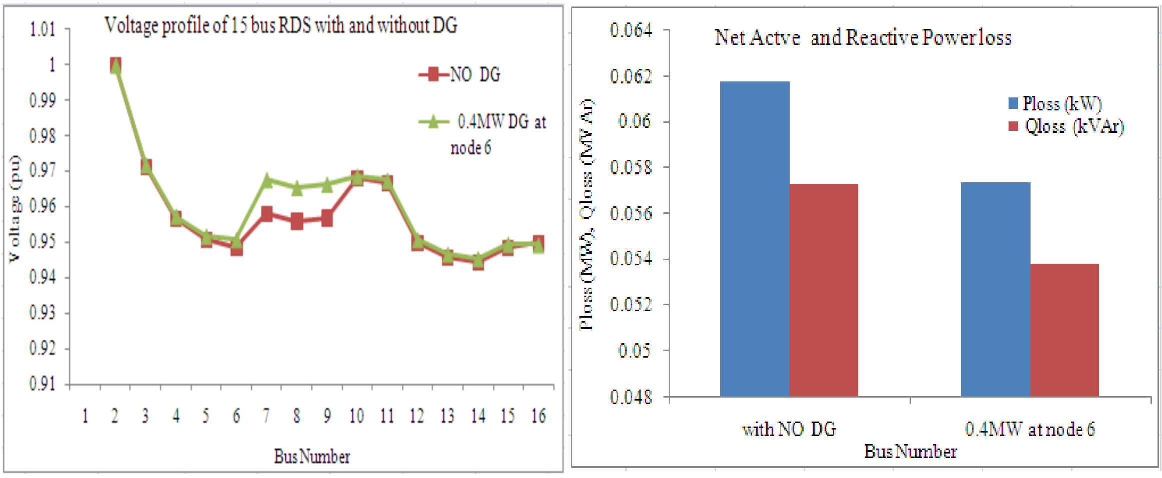
Step 9: Print the results.

4. Test system

In this work, 15 buses, 11KV radial distribution system connected with substation is taken as the test system (See Fig. 2). This system consists of 4 main feeders and 10 lateral feeders and the total active and reactive load connected to this system are 1.2264 MW and 1.251 MVAr respectively. Power factor of the load is treated as 0.7. Loads represented as constant power and shunt capacitances are neglected. It is assumed that the three phase radial distribution networks are balanced and loads are assumed to be constant. The substation consists of a step down transformer with voltages 230/11 kV.

The substation is taken as the slack bus and its voltage is taken as 1 pu. It is assumed that the slack bus generates real and reactive power required to meet transmission losses. The algorithm is written in Matlab and simulation is carried out based on Eqs. (10)-(12) to find power losses (Eq. 13) and the voltage at each bus and thereby the voltage stability of the test system is analyzed.

Voltage stability can be assured only with the integration of suitable capacity of DG at optimum access point by reducing losses. To obtain a voltage profile and power losses, load flow



(a) Voltage profile (1) NO DG (2) 0.4 MW DG placed at node 6

(b) Active and reactive power loss (1) NO DG (2) 0.4 MW DG placed at node 6

Fig. 3 Voltage profile and power loss of 15 bus radial distribution system

studies are to be conducted by placing different capacity of DG at each node. The main information obtained from the load flow study are magnitude, phase angle of the voltage at each bus, real and reactive power flowing in each line and hence, total power losses. Since the network is radial in nature, there is not much variation in phase angle.

Genetic Algorithm is used to obtain the capacity of DG at optimum access point. By using BFS algorithm and GA, voltage profile and power loss, and the optimum size of DG placed at the optimal location is found out.

5. Results and discussions

The proposed algorithm, GA based BFSA have been applied to an 11KV, 15 bus radial distribution system with constant load condition. The test results are compared with a sensitivity analysis approach in which the size of DG is varying from 10 to 100% of total connected load.

5.1 Radial distribution system with NO distributed generation

In this case, load flow analysis based on BFSA algorithm has been carried out in a 15 bus radial distribution system to find the voltage profile, net active and reactive power loss without the integration of DG. Load flow simulation is carried out in MATLAB environment.

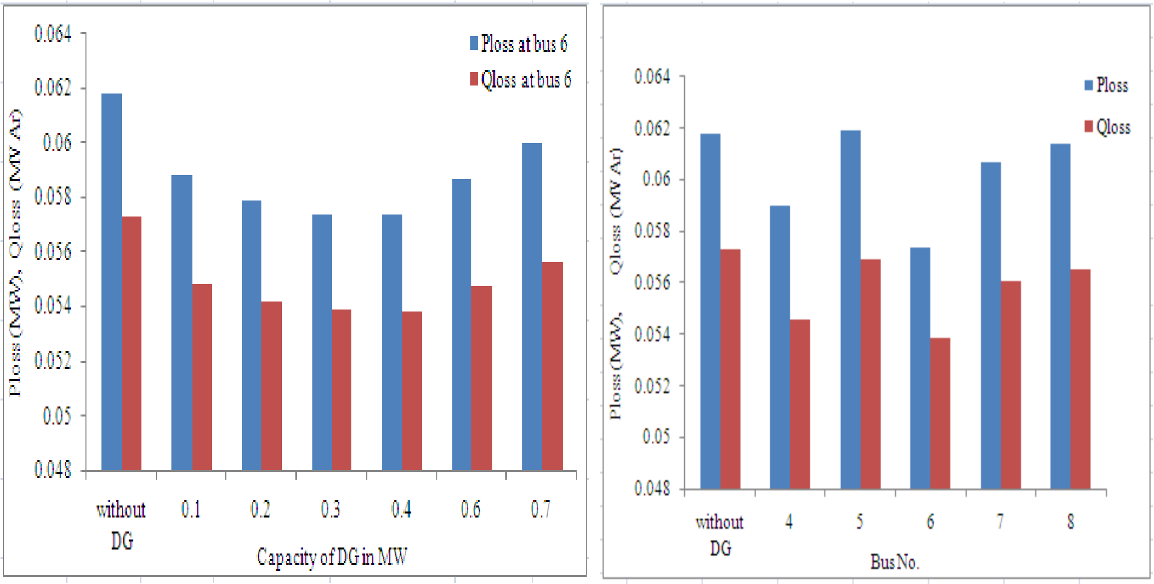
From Fig. 3(a), it is found that far end buses 12, 13, 14 and 15 with respect to the substation are suffering from under voltages. Since it is a radial distribution system, the feeder far away from the slack bus or substation suffers from high voltage regulation. In comparison with the slack bus of voltage 1 pu (11 KV), the bus number 13 is having a minimum voltage of 0.9445 pu (10.38 KV) with a drop of 5.55%. This bus is far away from the substation and the connected load is very less, 0.063 MW only. The bus having a maximum voltage of 0.9713 pu (10.68 KV) is bus number 2 with a drop of 2.87%. This bus is very near to the substation with the same connected load. Even for the same connected load, the bus at the far end is seriously affected in the voltage than the bus close to the substation. Moreover, the permissible limit of the minimum voltage is not in the range of ±5% (10.45 KV).

Fig. 3(b) shows that the net active power loss and reactive power loss are 0.06179 MW and 0.05729 MVAr respectively. The load of a distribution system always changes with customer demands. The power loss decreases with an increase in the distance of the feeder or bus from the substation or slack bus. This is mainly because of the low load power consumption as well as low amount of current flow through these branches. It is seen that 5.038% of connected active load occurred as net real power loss and 4.58% of connected reactive load as a net reactive power loss.

5.2 Radial distribution system with distributed generation

The voltage stability and power loss in Radial Distribution System (RDS) mainly depend on the location and sizing of DG. Better voltage regulation and voltage stability can be achieved only with minimizing power losses. The voltage at each node, net active and reactive power losses are computed by allocating different sizes of DG from 0.1 MW to 1.5 MW at each bus. GA algorithm is used to obtain the optimal access point and capacity of DG to improve the voltage profile and to reduce the active and reactive power loss. The selection of GA is Roulette wheel, crossover, mutation and population taken for GA are 1 point crossover with a crossover rate of 0.95, bitwise mutation with a mutation rate of 0.05 and 30 individuals respectively.

Using the MATLAB program, net real and reactive power losses are obtained for different size of DG placed at each bus. From this, it is found that as the capacity of DG increases, firstly, power losses decreases and then increases. It should be noted that as the size of DG increases or decreases, negative impact on the system is the result. It is observed that node 6 having less power



(a) Voltage profile when different size of DG placed at node 6

(b) Active and reactive power loss when 0.4MW DG placed at different nodes

Fig. 4 Voltage profile and power loss of 15 bus Radial Distribution System with integration of DG loss. Fig. 4(a) shows the comparison of active and reactive power loss for different size of DG placed at node 6 with NO integration of DG. In this regard, it is pointed that 0.4 MW DG placed at node 6 having a minimum power loss.

MATLAB program is carried out to find the power loss of the system by installing 0.4 MW DG at different buses. Fig. 4(b) shows the comparison of power loss at selected buses with NO integration of DG. The power is high for other buses than the selected buses. From this, it clearly means that bus 6 having minimum losses compared with other buses.

Fig. 3(b) depicts that the active power loss, reduced from 0.06179 MW to 0.05738 MW and reactive power loss from 0.05729 MVAr to 0.05385 MVAr with the integration of 0.4 MW capacity of DG placed at bus 6. With the integration of single DG, reduction of active power loss is found to be about 4.73% for bus 6. The corresponding reduction in reactive power loss is found to be 6.0%. The analysis clearly states that real and reactive power losses are considerably reduced with the integration of proper size of DG at optimal location.

Fig. 3(a) shows that the voltages of the most affected buses are much improved with the integration of single DG. In this case, with respect to slack bus, the minimum and maximum voltages are 0.9452 pu (10.4 KV) at bus 13 and 0.9718 pu (10.69 KV) at bus 2 respectively. The percentage reductions in voltages are 5.48% and 2.82% respectively compared with slack bus voltage. Hence, it is clear that the minimum and maximum voltages at bus 13 and 2 are recovered with 0.074% and 0.05% with the integration of 0.4 MW DG at bus 6. Now, only 13 and 14 buses are suffering from under voltage.

The introduction of single DG of size 0.4 MW at bus 6 resulted in benefits like improvement of voltage profile and reduction of power losses. When the capacity and location are optimized, the voltage profile is improved and hence it is established that the losses are reduced. And also, the voltage drop at bus 13 is reduced from 5.55% to 5.48%. Table 1 gives the overall result of the 15 bus radial distribution system with and without the integration of DG. The voltage profile as well as loss reduction can be attained with the help of integration of more number of DGs or by hybrid system rather than extending the infrastructure of the existing system.

It clearly explained that the size of DG of 32.62% of total connected load is placed on the node 6, results in a 7.13 % reduction in active power loss and 6% reduction in reactive power loss. It ratifies that total active power losses in the system can be reduced drastically by installing multiple DG’s at various potential locations.

5.3 Sensitivity analysis

An index named Sensitivity Analysis Factor (SAF) is derived for finding the optimal location

Table 1 Overall system parameters of 15 bus radial distribution system

System parameters	NO DG	Single DG
Active Power loss (MW)	0.06179	0.05738
Reactive Power loss (MVAr)	0.05729	0.05385
Minimum voltage (pu)	0.9445	0.9452
Location at min. voltage	13	13
Optimum location		6
Optimum Capacity		0.4

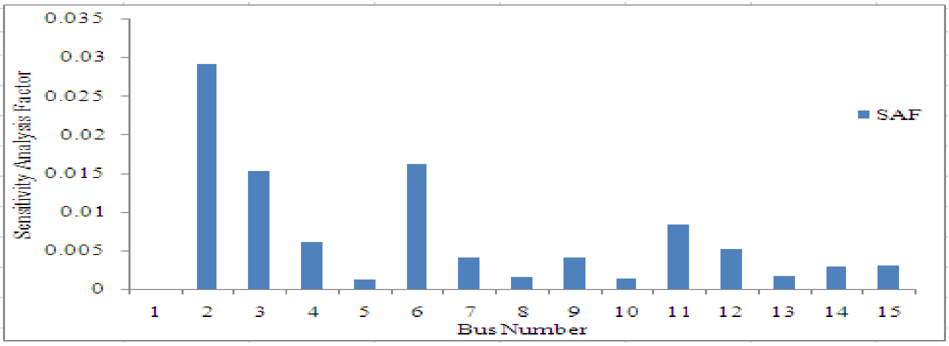


Fig. 5 Sensitivityanalysis factor of 15 bus system

of DG in a radial distribution system. Sensitivity Analysis Factor (SAF) which gives the priority list of buses having high voltage instability. As the load at the bus increases above a certain limit, there occurs a great chance of becoming a weak bus. This index is calculated for each branch and sorted from highest to smallest value. It gives the priority list for the location of DG. The DG should be placed at the end of the branch having highest SAF. Under stable operation, its value should be less than unity. This indicates that the maximum voltage instability occurs at the bus having highest index (Aman and Jasmon 2012).

For the bus having sending end node '*i*' and receiving end node '*j*'

$$P_{loss(j)} = \frac{[P_{eff}^{\,2}(j) + Q_{eff}^{\,2}(j)] * R[k]}{|(V[j])|^2} \tag{14}$$

where $P_{eff}[j]$=total effective active power supplied beyond the node '*j*'

$Q_{eff}[j]$=total effective reactive power supplied beyond the node '*j*'

$R[k]$=resistance of kth branch

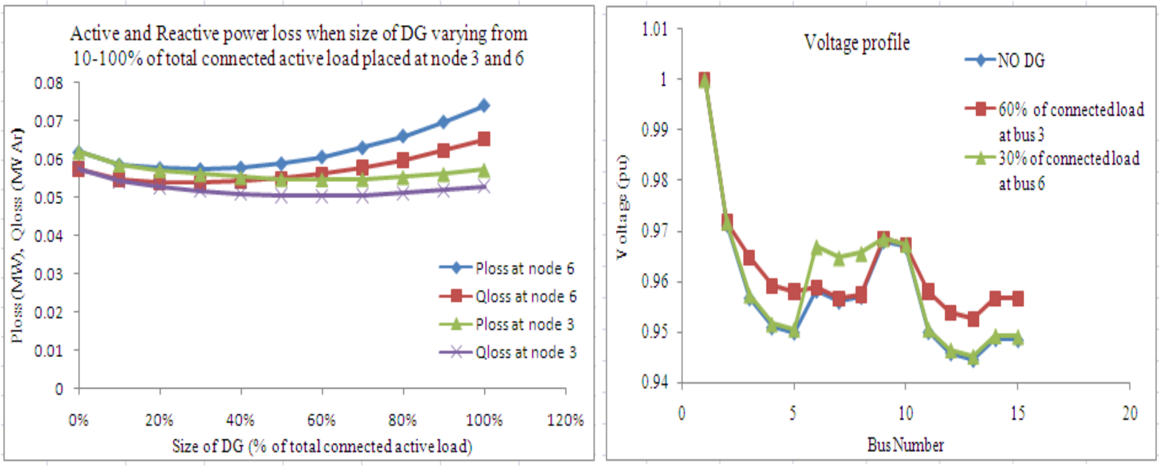
For system loss reduction to be maximized, the rate of change of P_{loss} with respect to the injected power becomes zero. From this, the Sensitivity Analysis Factor (SAF) is derives as

$$\partial P_{loss} \Big/ \partial P_{eff} = \frac{(2 * P_{eff}[j] * R[k])}{|V[j]|^2} \tag{15}$$

From this analysis shown in Fig. 5, it is found that bus 2 which is very near to the substation has the first priority. The bus near to the substation does not require active power supplementation. The bus numbers 3 and 6 have the second and third priorities which needs active power support.

Using this analysis, in order to get the exact size of DG, 10 to 100% of total connected load is taken as size of DG placed at nodes 3 and 6 of the test system. The total connected active load is 1.2264MW. The total power loss and voltage profile are computed by placing various sizes of DG at each node. Select the size of DG and bus number at which minimum power loss is the best location and optimal size of DG to improve the voltage profile.

From the load flow analysis, the minimum active and reactive power losses are found to be 0.054588 MW and 0.050277 MVAr respectively at node 3 when 0.736 MW DG (60% of connected load) connected to the test system. It is seen from Fig. 6(a) that minimum active and reactive power loss are obtained as 0.057342 MW and 0.053824 MVAr respectively, when 0.368



(a) Active and reactive power loss when size of DG varying from 10-100% of total connected active load placed at node 3 and 6

(b) Voltage profile (1) NO DG (2) 60% of connected load placed at node 3 (3) 30% of connected load placed at node 6

Fig. 6 Power loss and voltage profile 15 bus radial distribution system

Table 2 Loss savings in RDS with the integration of DG

Bus Location	Total Load (MW)	Size of DG (MW)	Losses before DG installation (MW)	Losses after DG installation (MW)	Savings (MW)
6	1.2264	0.368	0.06179	0.057342	0.004448
3		0.736		0.054588	0.007202

Table 3 Comparison between GA and case study

System parameters	GA	Sensitivity Analysis Approach
Active Power loss (Ploss) with NO DG (MW)	0.06179	0.06179
Reactive Power loss (Qloss) with NO DG (MVAr)	0.05729	0.05729
Optimum size of DG (MW)	0.4	0.368
Location of DG	6	6
Active Power loss with DG (MW)	0.05738	0.057342
% Reduction in Ploss	7.13	7.2
Reactive Power loss with DG (MVAr)	0.05385	0.053824
% Reduction in Qloss	6.0	6.05
Minimum voltage (pu) with NO DG	0.9445	0.9452
Location at min. voltage	13	13
% maximum voltage drop with NO DG	5.55	5.55
Minimum voltage (pu) with DG	0.9452	0.9452
% maximum voltage drop with DG	5.48	5.48
Grid Power with NO DG (MW)	1.28819	1.28819
Grid Power with DG (MW)	0.88378	0.915742

MW (30% of total connected load) is taken as the size of DG placed at node 6. From this analysis, it is observed that as the losses decreases, size of DG increases and vice versa.

The voltage profile shown in Fig. 6(b) depicts that voltage profile is improved in some buses when 30% of connected load is placed on node 6 and in other buses when 60% of connected load placed on node 3. It is observed that the size of DG is doubled when power loss decreases from 0.057342 MW to 0.054588 MW.

Table 2 shows the loss savings with the placement of single DG in 15-bus radial distribution system. It gives that the integration of 0.368 MW DG at node 6 gives a loss savings of 0.004448 MW and 0.736 MW DG at node 3 gives 0.007202 MW respectively. From the analysis, it is concluded that on the basis of optimum size of DG, 0.368 MW placed at node 6 is preferred for reduction of power losses and improves the voltage profile.

Table 3 gives the overall comparison between GA and sensitivity analysis approach. It is found that the results obtained from both approaches are same but sensitivity analysis gives exact size of real power support. Since the sensitivity approach identifies the proper weakest node among the different nodes, both required memory space and computation time are less compared to GA approach. Moreover, the sensitivity analysis approach and Matlab simulation results conclusively prove that the addition of active power in terms of other alternatives such as multiple DG can help in acquiring of better voltage stability.

6. Conclusions

The crucial factors for loss minimization in DG integrated network are mainly size and location of DG. In this paper, a simple and efficient analytical approach BFSA is proposed to assess the impact of DG in a radial distribution network. This approach gives voltage profile and power losses by placing different size of DG at different locations. Genetic algorithm is used to obtain the optimal location and proper size of DG at which minimum power loss. The results show that the proposed method provides useful information regarding the optimal location and size of DG to give better voltage profile and reduced losses. Total active power loss is 0.06179 MW and reactive power loss is 0.05729 MVAr without the integration of single DG. By installing single DG of 0.4 MW DG at bus 6, the total active power loss is reduced to 0.05738 MW and reactive power loss to 0.05385M VAr with a maximum saving of 0.00441 MW. Sensitivity analysis factor is used to establish the authenticity of the optimal location obtained from Genetic Algorithm. This factor gives the best location of DG, in the order of 2, 6, 3, 11, out of which 2 is very near to the substation. Hence, the next best location is bus 6. Sensitivity analysis gives the same bus number obtained from GA based BFSA algorithm. It is concluded that integration of 0.4 MW DG at bus 6 is the best size and position for better voltage profile and reduced losses. Moreover, the integration of multiple DGs at potential locations gives better improvement in voltage profile as well as considerable decrement in system losses.

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